THE EFFECT OF RETROCUES ON CDA AND VISUAL WORKING MEMORY CAPACITY IN YOUNG ADULTS

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THE EFFECT OF RETROCUES ON CDA AND VISUAL WORKING MEMORY CAPACITY IN YOUNG ADULTS

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ABSTRACT

Visual working memory is a system through which we retain information about objects in our visual environment. Through this system, information is stored so that it can be recalled or manipulated within the first few seconds of perception. Individual working memory capacity underlies numerous aspects of cognition including visual search, attentional processes, and concentration, and can predict performance on cognitive measures. Working memory is used in many everyday tasks and has implications in aging and the pathology of diseases. Contralateral Delay Activity (CDA) is a form of event-related potential measured with electroencephalography (EEG) that is thought to be modulated by the number of items held in working memory. In a related area of study, retrocues are attentional tools that are used to help individuals recall information from working memory. Retrocues are thought to improve visual working memory capacity by enhancing the active maintenance of relevant information held in working memory. This study attempts to show a relationship between retrocue usage and the CDA. We predict that retrocue trials will improve young adults' performance on a working memory task and will enhance the CDA, showing that retrocues are an effective modulator of the CDA.

CHAPTER 1

INTRODUCTION

Visual Working Memory

Visual working memory is a system through which we retain information about objects in our visual environment (McCollough et al., 2007). We use working memory in numerous everyday tasks, such as crossing the street and speaking in front of an audience (Makovski et al., 2008). This information is stored in such a way as to be easily recalled or manipulated within the first few seconds after we perceive an object. Specifically, working memory is thought to be a fundamental process that supports numerous aspects of cognition including visual search, attentional processes, and concentration (Huettig et al., 2010). The capacity of working memory varies across individuals, and has shown to be a key predictive indicator of performance on various cognitive measures (Kyllonen and Christal, 1990; Kane and Engle, 2003; Daneman and Carpenter, 1980).

In 2001, Vogel, Woodman, and Luck devised a simple test to determine the average capacity of visual working memory. Subjects were presented with an array of objects (colored squares) on a computer screen, followed by a blank screen "retention period" in which they were asked to remember the array. Subjects were then shown a test array of squares and asked if the test array was the same or different than the original array. Visual working memory was tested by varying the number of squares in each array, ranging from 1-10 squares. Based on the data, Vogel, Woodman, and Luck estimate that visual working memory capacity is roughly three items (Vogel, Woodman, and Luck, 2001).More recent studies show that the amount of visual information that can be actively held in visual working memory may be around four items (Fougnie and Marois, 2006).

The exact nature of the underlying cognitive processes is unknown, but it is commonly accepted that the capacity of working memory is an important factor in many aspects of daily life. Changes in working memory capacity are related to the normal aging process, but are also implicated in the pathology of diseases. Previous studies have demonstrated that working memory capacity can predict various personality disabilities and disorders, such as depression and schizophrenia (Swanson et al., 2010, Veer et al., 2010). Additionally, individual working memory capacity has been implicated in predictions of socioeconomic status and financial success through the study of disease states.

The study of working memory has been an important part of cognitive psychology due to the fact that this process is so integrated into everyday tasks. In the past two decades, an effective way to assess working memory has arisen through the analysis of event-related potentials (ERPs). ERPs are fluctuations in voltage that are time-locked to a particular physical or mental event. These fluctuations directly correspond to the activity of populations of neurons responsible for various cognitive processes. In 2000, Picton et al. described the methods through which the electrical information from these neurons can be collected from the scalp and extracted from an electroencephalogram (EEG) through filtering and signal averaging (Picton et al., 2000). In subsequent ERP studies, Drew et al. showed that these electrical signals can provide clear neurophysiological measures of the dynamic cognitive processes that underlie working memory (Drew et al., 2006). For example, using change detection tasks (a type of working memory task), recent ERP studies by Drew et al. have shown greater negativity in the ERP over the channels contralateral (opposite hemisphere) to the position of the to-be remembered visual stimulus. This difference in amplitude between contralateral and ipsilateral (same hemisphere) activity is referred to as contralateral delay activity (CDA), and is thought to be modulated by the number of items held in working memory (Robitaille and Jolicouer, 2006; Wolfe, 2003; Downing, 2000; Hollingworth and Luck, 2009). Once the capacity of an individual's working memory is reached, the amplitude of the CDA reaches an asymptote. Because of this relationship, the CDA is thought to be a feasible neural correlate of an individual's working memory capacity (Drew and Vogel, 2008; Ikkai et al., 2010). This study will use the CDA to quantify changes in working memory capacity due to experimental manipulations.

Retrocues in Working Memory Tasks

Working memory tasks are frequently used to assess individual working memory capacity in a laboratory setting. In a working memory task, subjects are presented with a series of stimuli and then asked to recall information about them at a later time. Retrocues are attentional cues used to orient subjects' attention to the location at which a stimulus was previously presented. The most common example of a retrocue used in current research is an arrow that reminds subjects of a previously cued location. In addition to the first cue which directs the participant to a particular side of the visual display, the retrocue "reminds" the participant to retrieve information at a particular location on the pre-cued side. Recent behavioral studies show that the presence of retrocues leads to performance benefits in working memory tasks by helping subjects recall memory arrays that are no longer present, but can be brought back into mind (Griffin and Nobre, 2003; Landman et al., 2003; Lepsien and Nobre, 2007; Lepsien et al., 2005; Makovski and Jiang, 2007). Several possibilities for this performance increase have been cited, including the fact that attentional orienting may enhance the active maintenance of relevant items held in working memory (Lepsien and Nobre, 2007).

This study attempts to show a relationship between the use of retrocues and changes in the CDA in order to predict visual working memory capacity. If the CDA is a neural index of visual working memory capacity, and retrocues enhance visual working memory capacity, then retrocues should impact the size of the CDA. Based on this relationship, if the CDA proves to be an accurate representation of the effect of retrocues on visual working memory capacity then the CDA could potentially be used to measure visual working memory in other areas. Also, the CDA could be used as an effective tool to investigate additional means of improving visual working memory capacity. This study is a preliminary project contained within a broad study of experimental manipulations aimed at increasing working memory capacity in both younger and older adults. In the future, the knowledge gained from this study could be applied to research involving states of diminished memory capacity in adults, due to brain lesions, neurological disorders, or general aging. We hope that this research will provide a concrete way to directly measure changes in visual working memory capacity.

CHAPTER 2

HYPOTHESIS

This study will investigate an experimental manipulation known as a retrocue that works to enhance visual working memory capacity. Specifically, this study will attempt to investigate the relationship between retrocue usage and the Contralateral Delay Activity (CDA). To analyze this activity, working memory tasks will be used to measure retrocue effects, and EEGs will be conducted to measure the CDA. We hypothesize that retrocue trials will improve young adult's performance on working memory tasks and will enhance the CDA, showing that the CDA is an accurate measure of visual working memory capacity.

CHAPTER 3

MATERIALS AND METHODS

Eighteen healthy young adults (age range 18-22 years) took part in the study, and each was compensated $30 or 3 psychology credit hours for their participation. These participants were screened for any neurological disorders (e.g. tumor, bipolar depression) and all participants were right-handed, had normal color vision and normal or corrected-to-normal visual acuity. All participants were required to sign a consent form approved by the Georgia Institute of Technology's Institutional Review Board prior to participation.

Experimental Design

Participants completed working memory tasks on a computer in order to measure the effects of retrocue implementation on the CDA. EEGs were recorded while the participants completed the working memory task. The order of progression for each trial of the task is shown in Figure 1 below.

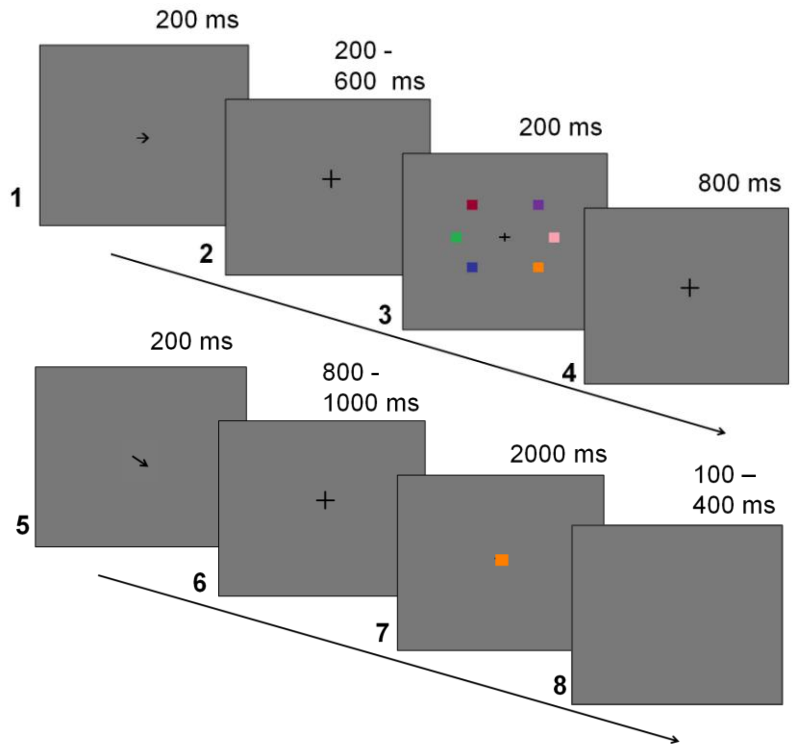


Figure 1. Trial progression for the working memory task.

Each square in Figure 1 represents a separate computer screen, shown one after the other. Each trial began with a pre-cue arrow displayed for 200 ms directing the participant to focus their attention toward one side of the screen (1). A fixation cross was displayed for either 200 ms, 400 ms, or 600 ms immediately after the pre-cue disappeared in order to direct the participant's vision to the center of the screen (2). Participants were instructed to focus on the center of the screen throughout the trial, but to orient their attention to the specified side of the screen as much as possible without moving their eyes. The memory array of colored squares was then presented for 200 ms (3), and then another fixation cross was presented for 800 ms (4). Each memory array consisted of 2-4 colored squares on both the left and the right side of the computer screen (Figure 2). The colored squares were presented on a gray background, and were black, white, green, blue, red, purple, yellow, or orange.

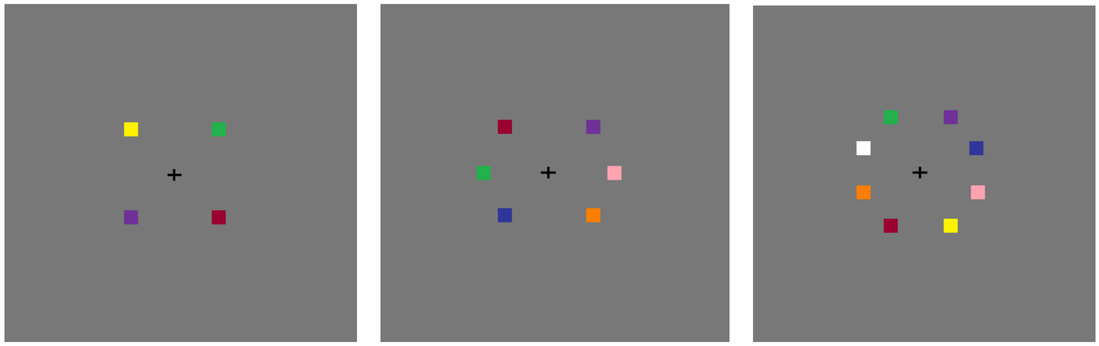


Figure 2: Memory array stimuli placement.

After the 800 ms fixation delay period, for half of the trials, an arrow directing the participant to remember one of the objects on the originally cued side of the screen (the retrocue) appeared for 200 ms (5). For the other half of the trials, another neutral fixation cross appeared on the screen instead (Figure 3). Then, another jittered retention interval with a fixation cross appeared for 800 ms, 900 ms, or 1000 ms (6). After the final retention interval, a test item consisting of a single colored square in the center of the screen was shown for 2000 ms (7). During the test interval, subjects were asked to press "1" on the keyboard to indicate if the test item was included in the memory array, and press "2" on the keyboard if the test item was not included in the memory array. For example, in the trial above, the correct answer would be "1", for "yes." Accuracy was emphasized more than speed of response, but participants were asked to answer as quickly as possible. Participants were asked to make their responses during the 2000 ms presentation of the test item. Trials were separated by a plain gray background to differentiate between the end of a test interval and the beginning of a new trial (8). This background interval was jittered and ranged from 100-400 ms.

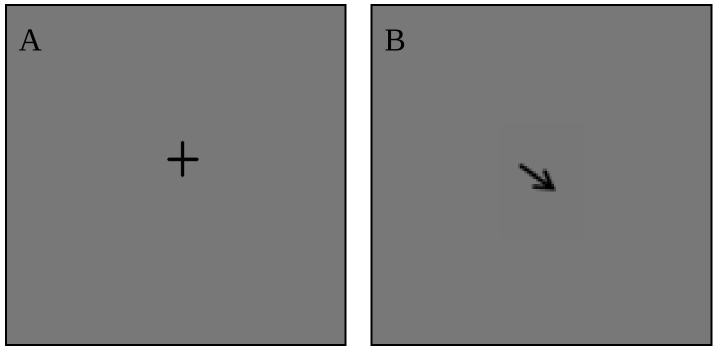


Figure 3. (A) Neutral cue, (B) Retrocue.

There were 756 total trials in this experiment, divided into 12 blocks of 63 trials each. There were 378 trials with a test item that was originally included in the memory array (i.e. match), and 378 trials with a test item that was not originally included in the memory array (i.e. non-match: for example, a blue square test item when no blue square was previously presented). Half of each of these types of trials were neutral and the other half were retrocue trials, such that there were 189 neutral match trials, 189 neutral non-match trials, 189 retrocue match trials, and 189 retrocue non-match trials. The number of squares in each array was in equal proportions throughout the experiment. Each block of 12 trials lasted approximately 5 minutes, and a practice session lasting approximately 7 minutes preceded the start of the trials. This practice session gave examples of trials with 2,3, and 4 squares on each side, and showed both match and non-match trials. The participant was shown “Correct!” or “Incorrect!” after each response in order to provide feedback on accuracy. If the participant did not answer during the 2000 ms test interval, he or she was shown “No response detected” to indicate that no valid response was received. The total experiment, including preparation time for the EEG, lasted approximately three hours.

EEG Acquisition and Analysis

Scalp-recorded EEG data was collected from 32 Ag-Ag/Cl electrodes using an ActiveTwo amplifier system (Biosemi, Amsterdam, Netherlands). Two additional electrodes were placed on the left and right mastoid processes and used subsequently as off-line references. Four additional electrodes were placed above and below the left eye and on the outer canthi of the left and right eyes to record vertical electrooculogram (VEOG) and horizontal electrooculogram (HEOG) data, respectively. EEG data was recorded continuously with 24 bit resolution and a sampling rate of 526 Hz, using the program Actiview (Biosemi, Amsterdam, Netherlands). Offline, data were referenced to the mastoids and were digitally band-pass filtered between 30Hz and .01Hz.

Prior to segmentation, eye movements were removed from the data using a method based on principle component analysis, similar to the method described by Berg and Sherg (Berg and Sherg, 1994) and is available in EMSE version 5.4 BETA 2. Extensive analysis of this method determined that there was no reduction in waveform resolution. Epochs containing any uncorrected artifacts (± 100μV) were removed. Also, trials with incorrect behavioral responses were discarded. ERP segments of 2000 ms including 200 ms prestimulus baseline, timelocked to stimulus onset, were created and averaged separately for each participant, electrode, and condition.

CHAPTER 4

RESULTS

Data from the fourteen subjects with good behavioral performance (< 80% accuracy) and clean ERP data were examined for behavioral and electrophysiological effects.

Behavioral Results

Participants showed higher accuracy for retrocue trials compared to neutral trials across all memory array loads. As shown in Figure 3, the mean percentage of correct responses in retrocue trials was 94%, compared to a mean percentage of 91% in neutral trials, across all loads. Overall decreased accuracy was seen as memory array load increased.

Based on the ANOVA of load (2,3,4) x cue type (Neutral,Retrocue), the main effect of load [$F\ (2,13) = 21.223$, $p < .001$] indicated that participants were more accurate as load decreased. The main effect of cue type [$F\ (1,13) = 9.485$, $p = .041$] indicated that across all loads, the retrocue improved accuracy. Subsidiary ANOVAs showed a marginal interaction between cue type at load 2 vs. load 3 [$F\ (1,13) = 3.018$, $p = .103$]. The interaction between cue type at load 3 vs. load 4 was not significant [$F\ (1,13) = 1.496$, $p = .243$], nor was the interaction between cue type at load 2 vs. load 4 [$F\ (1,13) = .110$, $p > 0.5$]

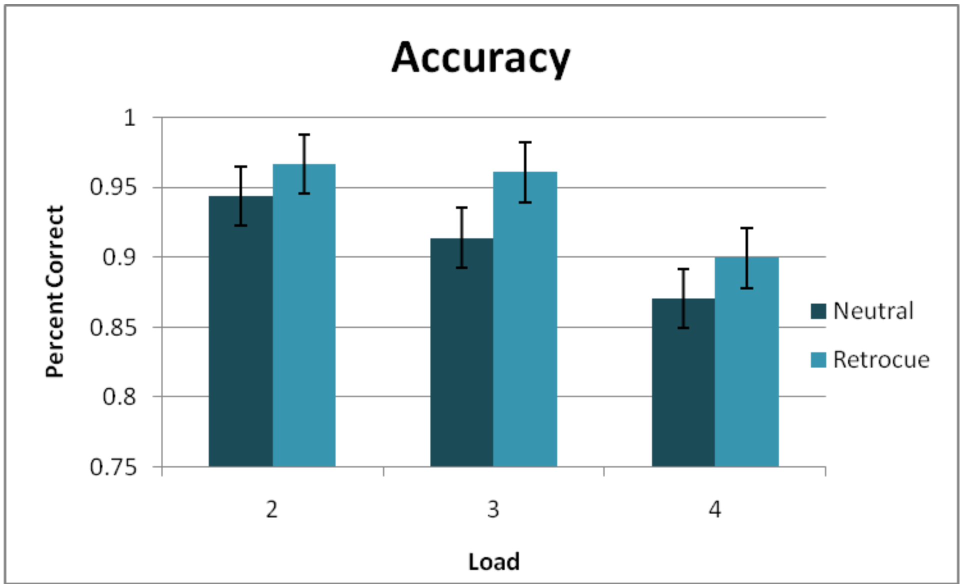


Figure 4: Accuracy data in terms of the load of items in the memory array.

Response time decreased for all loads in the retrocue condition, as evidenced by a main effect of cue type [$F (1,13) = 35.367$, $p < .001$]. The effect of load on response times was not significant [$F (2,13) = 0.520$, $p > 0.5$] suggesting that response times did not reliably differ as a function of load.

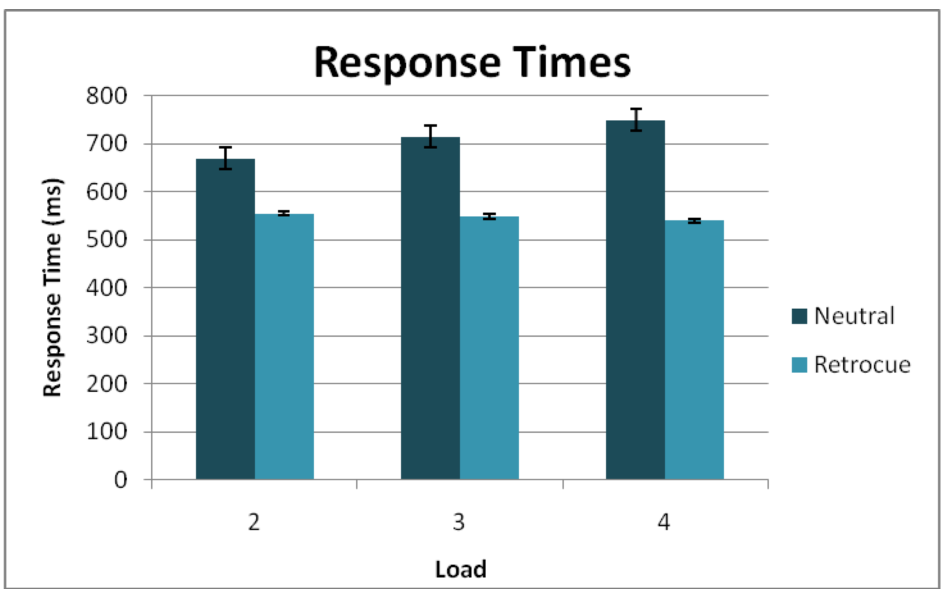


Figure 5: Response time data in terms of the load of items in the memory array.

The behavioral pattern of observed results was consistent with previous studies showing increases in accuracy and decreases in response time as a function of retrocue implementation (Griffin and Nobre, 2003; Landman et al, 2003; Makovski and Jiang, 2007).

Electrophysiological Results

The event-related potentials were computed by averaging the EEG from 200 ms before the onset of the memory array (pre-stimulus baseline) and ending 1800 ms after the onset. The waveforms for the Neutral Left and Neutral Right conditions for all posterior electrode sites are shown in Figure 5A. The waveforms for the Retrocue Left and Retrocue Right conditions for all posterior electrode sites are shown in Figure 5B. In this figure and all subsequent figures, negative voltage is plotted upwards. As shown in the figure, the activity for the two conditions diverged after approximately 300 ms at the lateral posterior electrode sites, and this difference lasted through the onset of the test square (up to approximately 1500 ms). At the posterior electrode sites along the left hemisphere (particularly CP5 and P7), the voltage observed for the right condition was significantly more negative than for the left condition. Conversely, at the posterior electrode sites along the right hemisphere (particularly CP6 and P8), the voltage observed for the left condition was significantly more negative than for the right condition. This difference in negativity, opposite for the two hemispheres, is representative of the Contralateral Delay Activity.

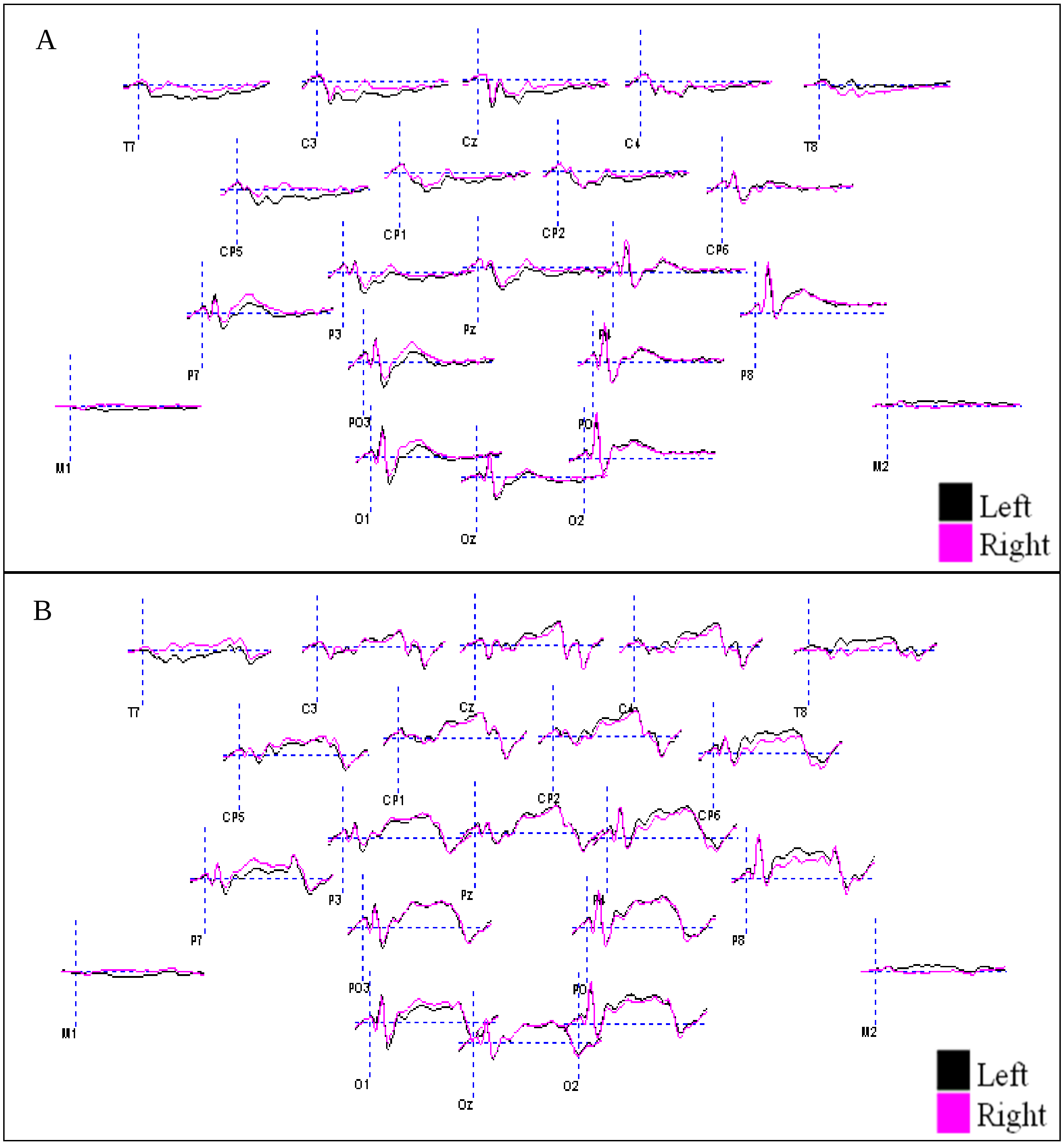


Figure 6: (A) Grand averaged waveforms for Neutral Left condition (all loads) and Neutral Right condition (all loads) at posterior electrode sites. (B) Grand averaged waveforms for Retrocue Left condition (all loads) and Retrocue Right condition (all loads) for posterior electrodes.

Figure 7 shows the grand-averaged contralateral and ipsilateral activity at posterior electrode site CP5/CP6 collapsed across side for all conditions. This collapsed waveform allows for a convenient analysis of the CDA as a function of load and cue type and is consistent with the previous literature (McCollough et al., 2007). We created contralateral waveforms for this electrode site by averaging two waveforms: 1) the activity recorded at the right electrode site (CP6) when subjects were cued to remember the left side of the memory array, and 2) the activity recorded at the left electrode site (CP5) when subjects were cued to remember the right side of the memory array. We created ipsilateral waveforms for this site by averaging the opposite two waveforms: 1) the activity recorded at the right electrode site (CP6) when subjects were cued to remember the right side of the memory array, and 2) the activity recorded at the left electrode site (CP5) when subjects were cued to remember the left side of the memory array. As shown in the figure, the contralateral activity diverges from the ipsilateral activity approximately 300 ms after the onset of the memory array. This difference persisted until approximately 1500 ms after onset. As seen in the figure, negative activity was greater in the Retrocue condition for all loads compared to the Neutral condition. This is most likely due to the fact that participants were anticipating the onset of the retrocue for retrocue trials. The largest CDA is observed for the Retrocue load 3 condition (Figure 7D). The blue line at 1000 ms represents the onset of the Neutral cue or Retrocue.

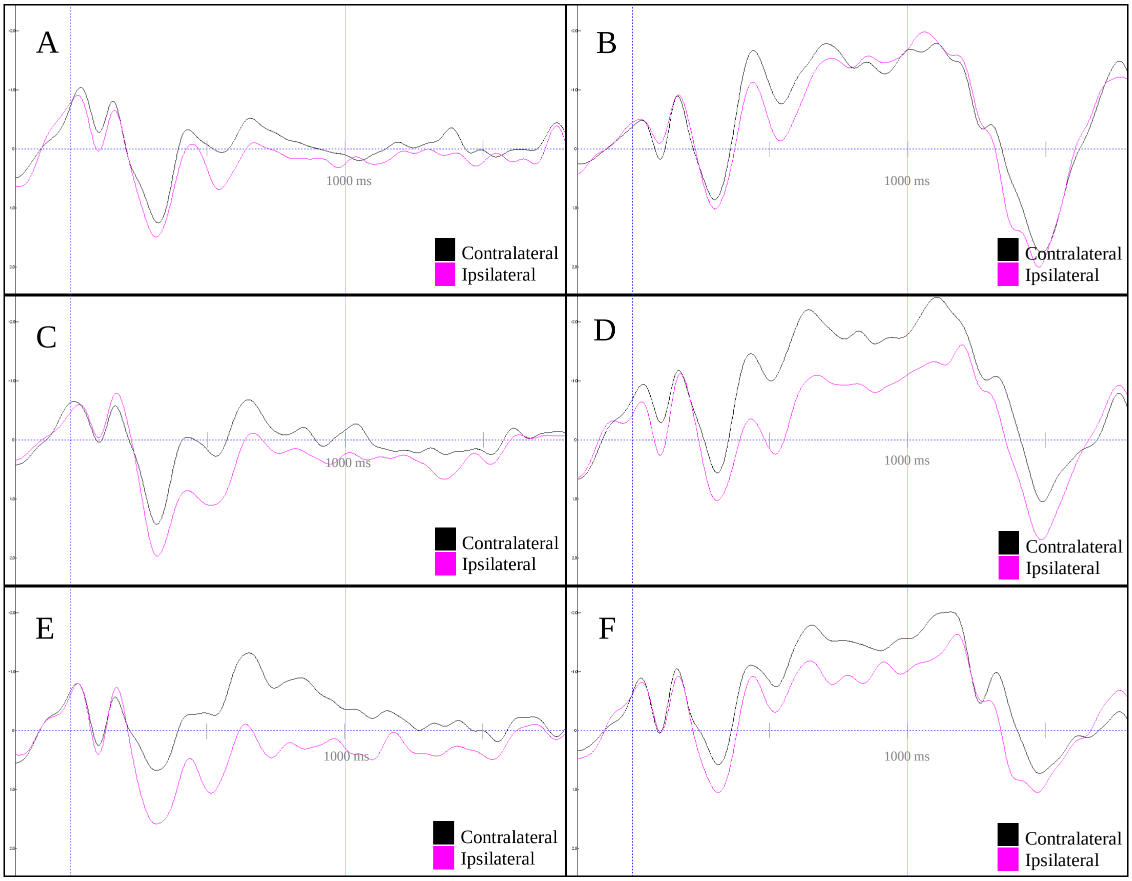


Figure 7: Contralateral and ipsilateral activity at electrode side CP5/CP6 time-locked to memory array and collapsed across side. (A) Neutral load 2, (B) Retrocue load 2, (C) Neutral load 3, (D) Retrocue load 3, (E) Neutral load 4, (F) Retrocue load 4.

Based on our observations of the effects for individual conditions, we created difference waves in which the ipsilateral activity was subtracted from the contralateral activity. These difference waves provide a direct measure of the contralateral delay activity and allow us to compare this size of the CDA across all loads and cue types. As in previous figures, the CDA seems to emerge at approximately 300 ms and persist through the onset of the test square. For the Neutral condition, the CDA appears to be load-modulated, being largest for load 4 and smallest for load 2 (Figure 8A). However, for the Retrocue condition, the CDA is largest for load 3, followed by load 4 and then load 2 (Figure 8B). To establish the significance of these effects, we first divided the data into two time windows: 300 ms – 900 ms and 900 ms – 1500 ms, consistent with the previous literature. For each time window, we performed a load (2,3,4) x cue type (Neutral, Retrocue) x side (Contralateral, Ipsilateral) ANOVA to test for main effects. For the 300 ms – 900 ms time window, these ANOVAs showed a main effect of cue type [F (1,13) = 15.540, p = .002] and a main effect of side [F (1,13) = 8.270, p = .013]. We also found a marginal interaction of load x cue type x side [F (2,1,13) = 3.205, p = .076], and subsidiary ANOVAs confirmed that the interaction of cue type x side was marginally significant for load 4 [F (1,13) = 4.601, p = .051]. This suggests that while the CDA was present for all conditions, as indicated by the main effect of side, the CDA was statistically larger for Neutral than Retrocue load 4 trials. The lack of cue type x side interactions for loads 2 and 3 suggests that the CDA did not reliably differ as a function of cue type for these load types. For the 900 ms – 1500 ms time window, the ANOVAs again showed a main effect of cue type [F (1,13) = 11.470, p = .005] and a main effect of side [F (1,13) = 6.964, p = .020]. We found a significant interaction of load x cue type x side [F (2,1,13) = 4.086, p = .034], and subsidiary ANOVAs showed a significant interaction of cue type x side for load 3 only [F (1,13) = 5.615, p = .034].These results suggest that the CDA, although beginning to dissipate in this time window, was reliable for all loads. The interactions suggest that the CDA was statistically larger for Retrocue than Neutral cue load 3 trials. The lack of cue type x side interactions for loads 2 and 4 suggests that the CDA did not reliably differ as a function of cue type for these load types in this later time window.

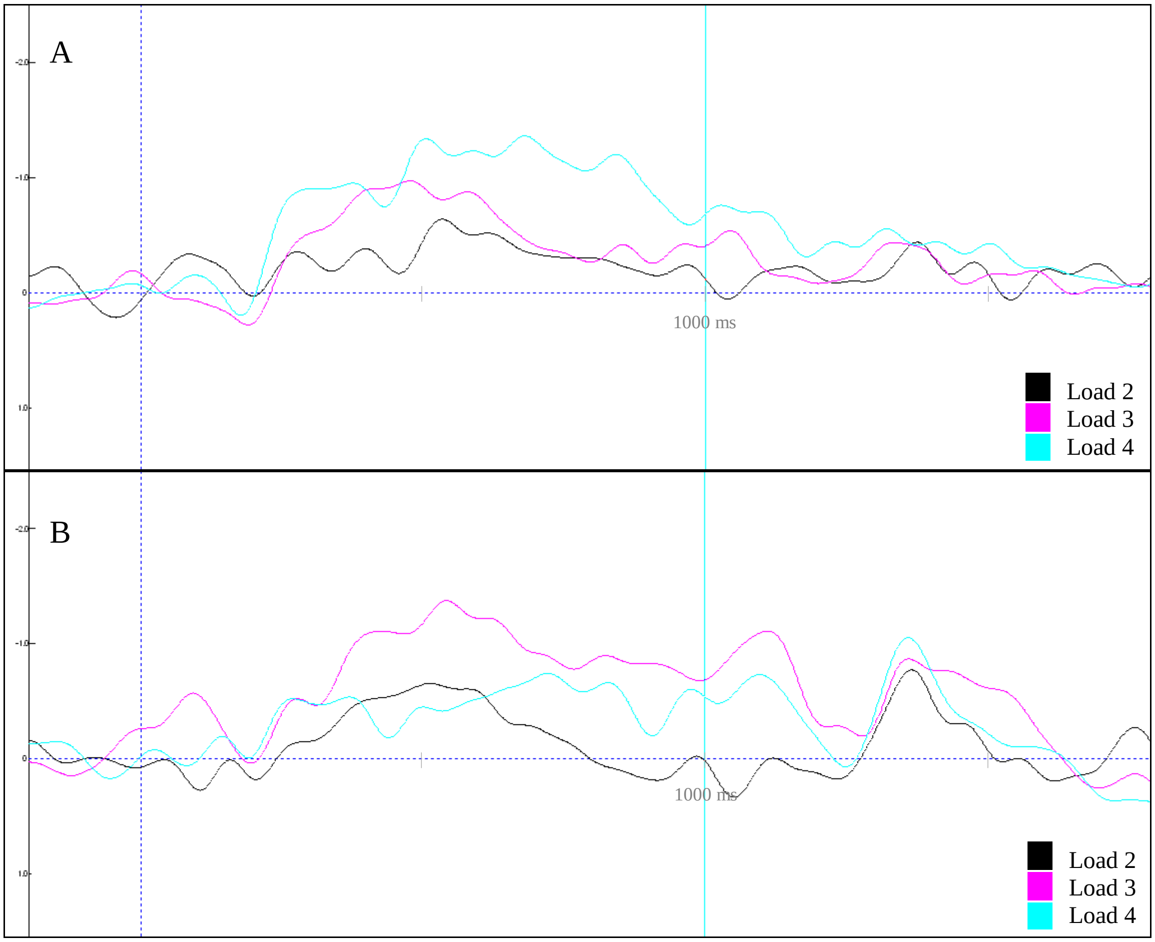


Figure 8. (A) Neutral Right – Neutral Left difference waves for loads 2, 3 and 4 at electrode site CP5/CP6 collapsed across hemisphere. (B) Retrocue Right – Retrocue Left difference waves for loads 2, 3 and 4 at electrode site CP5/CP6 collapsed across hemisphere.

CHAPTER 5

DISCUSSION

In this study, we used behavioral measures and event-related potentials to assess the relationship between the contralateral delay activity and retrocueing within the scope of visual working memory processes. In particular, we manipulated memory array load to identify neural activity as a function of the number of items held in visual working memory and retrocue usage.

Behavioral Discussion

Consistent with our predictions, both accuracy and response time improved as a function of retrocue usage. Accuracy significantly increased across all loads with retrocue usage, demonstrating that retrocues helped maintain the relevant information about the previously presented memory array more accurately in visual working memory, at least for the duration of the working memory task. Strikingly, the largest increase in accuracy between Neutral and Retrocue trials was observed for load 3. This indicates that the retrocues helped increase working memory capacity most effectively for memory arrays of 3 items. One possibility, which requires further exploration, is that some participants' memory capacity was maximal for load 3. Thus, if load 4 is beyond a person's capacity, the effect of retrocueing may be minimal. We are currently following up this hypothesis with a larger sample of participants to be able to examine individual differences in working memory capacity.

Response times decreased across all loads with retrocue usage, demonstrating that retrocues helped recall the information about the memory array more quickly from visual working memory. There was not a significant difference of response times across loads, indicating that response times were not greatly affected by an increased or decreased memory array load.

Electrophysiological Discussion

Opposite negative waveforms were observed on left- and right-sided electrodes at lateral posterior sites, which is consistent with the setup of the visual system. (i.e., neural processing takes place mostly on the opposite hemisphere of the brain from the perceived stimuli). Contralateral waveforms showed a greater negative activity for both the left and right sides, and appeared as opposite patterns on each side. The CDA emerged around 300 ms after the onset of the memory array, and persisted until approximately 1500 ms after onset. The increase in measured CDA for Retrocue trials suggests that the CDA is being modulated by retrocue usage.

The ERP data suggests that the activity due to the Neutral condition was modulated by load, but that the activity due to the Retrocue condition was greatest at a load of 3 items. The 900 ms – 1500 ms time window showed a significant interaction of cue type x side at load 3, demonstrating that the contralateral and ipsilateral waveforms are significantly different due to retrocue usage.

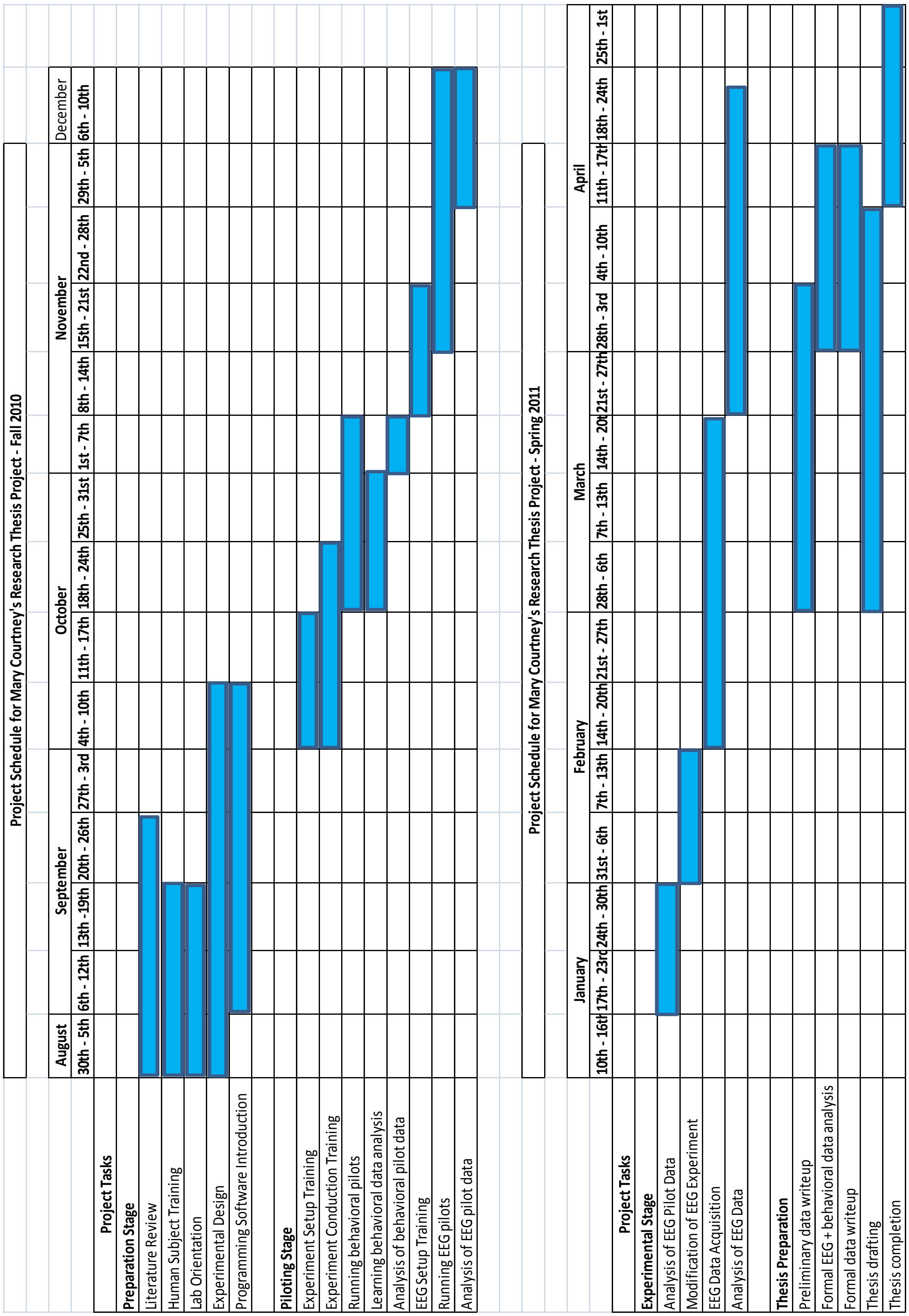
An interesting interaction can be observed upon comparison of the behavioral data and ERP data. The large increase in accuracy visually observed for load 3 corresponds to the largest CDA observed for load 3 Retrocue trials. These data together suggest that for the participants tested, the capacity of visual working memory was maximal at 3 items, at least on average. We believe that a more robust interaction of CDA and accuracy could be seen with a larger sample of participants.

General Discussion

The main objective of this study was to describe the effect of retrocues on the contralateral delay activity and visual working memory capacity in healthy young adults. We designed a working memory task in order to examine the properties of the CDA and compare it to the observed visual working memory capacity in our participants. We found that retrocues enhanced the CDA across all memory array loads, but particularly for a load of 3 items. This finding, in conjunction with the observed accuracy data for load 3, suggests that retrocues affect visual working memory most at a load of 3 items. This in turn suggests that the average working memory capacity limit for this task was 3 items and that at greater loads, when capacity has already been "maxed out," the retrocue had little to no effect on accuracy.

Together, the behavioral and electrophysiological results suggest that the contralateral delay activity is a robust neural correlate of visual working memory capacity. The results also suggest that retrocues are capable of increasing this visual working memory capacity across all individuals. Now that these findings have been characterized in healthy young adults, this experiment can be replicated in individuals with memory decay due to aging, disease, or other degenerative factors. We have shown that retrocues increase both the CDA and visual working memory, and so now these tools can be studied in older adults to determine their overarching effect in visual working memory processes.

WORK PLAN


Project Schedule for Mary Courtney's Research Thesis Project - Fall 2010
Project Tasks
August
September
October
November
December
30th - 5th
6th - 12th
13th -19th
20th - 26th
27th - 3rd
4th - 10th
11th - 17th
18th - 24th
25th - 31st
1st - 7th
8th - 14th
15th - 21st
22nd - 28th
29th - 5th
6th - 10th
Preparation Stage
Literature Review
Human Subject Training
Lab Orientation
Experimental Design
Programming Software Introduction
Piloting Stage
Experiment Setup Training
Experiment Conduction Training
Running behavioral pilots
Learning behavioral data analysis
Analysis of behavioral pilot data
EEG Setup Training
Running EEG pilots
Analysis of EEG pilot data
Project Schedule for Mary Courtney's Research Thesis Project - Spring 2011
Project Tasks
January
February
March
April
10th - 16th
17th - 23rd
24th - 30th
31st - 6th
7th - 13th
14th - 20th
21st - 27th
28th - 6th
7th - 13th
14th - 20th
21st - 27th
28th - 3rd
4th - 10th
11th - 17th
18th - 24th
25th - 1st
Experimental Stage
Analysis of EEG Pilot Data
Modification of EEG Experiment
EEG Data Acquisition
Analysis of EEG Data
Thesis Preparation
Preliminary data writeup
Formal EEG + behavioral data analysis
Formal data writeup
Thesis drafting
Thesis completion

REFERENCES

Berg, P. and Scherg, M. (1994). A multiple source approach to the correction of eye artifacts. *Electroencephalogr Clin Neurophysiol*, 90: 229-241.

Daneman, M. and Carpenter, P.A. (1980). Individual differences in working memory and reading. *J Verb Learn Verb Behav*, 19: 450-466.

Downing, P.E. (2000). Interactions between visual working memory and selective attention. *Psychol*, 11: 467-473.

Drew, T.W. and Vogel, E.K. (2008). Neural measures individual differences in selecting and tracking multiple moving objects. *J Neurosci*, 28(16): 4183-4191.

Drew, T.W., McCollough, A.W., and Vogel, E.K. (2006). Event-Related Potential measures of working memory. *Clinical EGG and Neuroscience*, 37: 286-291.

Fougnie, D. and Marois, R. (2006). Distinct capacity limits for attention and working memory. *Psychological Science*, 17: 526.

Griffin, I.C. and Nobre, A.C. (2003). Orienting attention to locations in internal representations. *J Cogn Neurosci*, 15: 1176-1194.

Hollingworth, A. and Luck, S.J. (2009). The role of visual working memory (VWM) in the control of gaze during visual search. *Attention Percept Psychophys*, 71: 936-949.

Huettig, F., Olivers, C.N. and Hartsuiker, R.J. (2010). Looking, language, and memory: Bridging research from the visual world and visual search paradigms. *Acta Psychol (Amst).*

Ikkai, A., McCollough, A.W. and Vogel, E.K. (2010). Contralateral delay activity provides a neural measure of the number of representations in visual working memory. *J Neurophysiol*, 103: 1963-1968.

Kane, M.J. and Engle, R.W. (2003). Working memory capacity and the control of attention: The contributions of goal neglect, response competition, and talk set to Stroop interference. *J Exp Psychol: Gen*, 132: 47-70.

Kyllonen, P.C. and Christal, R.E. (1990). Reasoning ability is (little more than) working memory capacity. *Intelligence*, 14: 398-433.

Landmann, R., Spekreijse, H. and Lamme, V.A. (2003). Large capacity storage of integrated objects before change blindness. *Vis Res*, 43: 149-164.

Lepsien, J. and Nobre, A.C. (2007). Attentional modulation of object representations in working memory. *Cereb Cortex*, 17: 2072-2083.

Lepsien, J. et al. (2005). Directing spatial attention in mental representations: Interactions between attentional orienting and working memory load. *Neuroimage*, 26: 733-743.

McCollough, A.W., Machizawa, M.G., and Vogel, E.K. (2007). Electrophysiological measures of maintaining representations in visual working memory. *Cortex*, 43: 77-94.

Makovski, T. and Jiang, Y.V. (2007). Distributing versus focusing attention in visual short-term memory. *Psychonomic Bulletin and Review*, 14(6): 1072-1078.

Makovski, T., Sunsman, R. and Jiang, Y.V. (2008). Orienting attention in visual working memory reduced interface from memory probes. *J Exp Psycho:, Learning, Memory, and Cognition*, 34: 369-380.

Picton, T.W. et al. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology*, 37: 127-152.

Robitaille, N. and Jolicouer, P. (2006). Fundamental properties of N2pe as an index of spatial attention: Effects of masking. *Can J Exp Psychol*, 60: 101-111.

Swanson, H.L., Kehler, P. and Jerman, O. (2010). Working memory, strategy knowledge, and strategy instruction in children with reading disabilities. *J Learn Disbil*, 43 (1): 23-47.

Veer, I.M. et al. (2010). Whole-brain resting state analysis reveals decreased functional connectivity in major depression. *Front Syst Neurosci*, 4: 41-53.

Vogel, E.K., Woodman, G.F. and Luck, S.J. (2001). Storage of features, conjunctions, and objects in visual working memory. *J Exp Psycho: Human Perception and Performance*, 27(1): 92-114.

Wolfe, J.M. (2003). Moving towards solutions to some enduring controversies in visual search. *Trends Cog Sci*, 7: 70-76.